

OLD DOMINION UNIVERSITY RESEARCH FOUNDATION

DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
COLLEGE OF ENGINEERING AND TECHNOLOGY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23508

GRADUATE ENGINEERING RESEARCH PARTICIPATION IN AERONAUTICS

By

A. Sidney Roberts, Jr., Principal Investigator

Final Report
For the period ended August 31, 1986

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

Under
Research Grant NGR 47-003-052
Dr. Samuel E. Massenberg
Office of University Affairs

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Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508



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SUMMARY

A unique, cooperative graduate engineering program has been supported for fifteen years under NASA Grant NGR 47-003-052. During the 15-year period of support, a spectrum of aeronautics-related research was conducted, and full-time graduate students obtained financial support and earned masters and doctoral degrees while working in the laboratories at NASA Langley Research Center, Hampton, Virginia. An abbreviated listing of primary program achievements is shown below.

- A program of joint student advisement was created involving NASA engineers and Old Dominion University engineering faculty.
- The graduate research participants, enrolled in graduate engineering degree programs, were awarded stipend and tuition support for a two-year period.
- Total enrollment in the grant program aggregated forty one (41) persons, and produced thirty one (31) graduate degrees (26 Masters, 5 Ph.D's).
- Approximately 50% of program graduates took up initial employment in or remain in an aeronautics-related enterprise.
- Research results, documented in theses, reports and papers, were produced in the following areas:
 1. Aircraft Design, Aerodynamics, Lift/Drag Characteristics
 2. Avionics: Aircraft Guidance and Control
 3. Fluid Mechanics: Inviscid flow, Boundary Layer and Gas Dynamic Studies
 4. Solid Mechanics: Composites, Shells, Beams Under Static, Impact and Transient Loading
 5. Instrumentation and Measurement Techniques

6. Thermophysical Properties Experiments
 7. Large Space Structures: Dynamics, Control, Reliability Analysis
 8. Earth Orbital Dynamics
 9. Environmental Engineering: Water Quality Modeling and Atmospheric Radiation Processes
- Of the total grant funds received, 50% went directly to student stipends; 12% was for indirect costs of grant management; and, the average cost of a graduate engineering degree was \$27,000.
 - Old Dominion University gained an enhancement of its graduate engineering programs during their formative years.

ACKNOWLEDGEMENTS

The principal investigator wishes to express thanks especially to the management personnel of the National Aeronautics and Space Administration, both at headquarters and at the Langley Research Center, for the foresight and confidence they demonstrated while maintaining this joint research and graduate study program for a period of fifteen years. Participating engineers at the center and faculty members at the university, most of whom are named in the report, deserve my thanks and the sincere appreciation for their efforts which I am sure would be expressed by the program graduates. It is only fitting to cite the progenitors of this program, Dr. Gennario L. Goglia of Old Dominion University and Dr. John E. Duberg of NASA Langley Research Center, both now retired from their respective institutions, but not from service to engineering research and higher education.

The Old Dominion University Research Foundation has served this grant program faithfully and well over the years, especially in regard to proposal and report preparation, payroll, and financial accounting. Many individuals there have aided the principal investigator, but for longevity and patience I particularly wish to thank Lynn R. James, formerly Director of Financial Services. Finally, the assembly of data for this final report, the organization and drafting of several sections, was a technical writing task ably performed by Amanda G. Roberts.

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INTRODUCTION

In the early nineteen seventies there was an evident and increasing need for joint participation in aeronautical education between universities, government, and industry. In 1974 this matter of concern was addressed by all three proponents at a joint NASA/University Conference on Aeronautics. Various steps were taken to enhance the production of engineering graduates who by maintaining great interest and sufficient preparation would assume responsible positions in a diverse aeronautics industry. One such cooperative graduate engineering program operated between the Louisiana State University in Baton Rouge and the NASA Johnson Space Center. The objective of that program was to provide a "hands-on" graduate engineering educational experience and to couple faculty, students and NASA engineers. The Old Dominion University School of Engineering proposed a similar yet distinct program which operated initially from the Virginia Associated Research Campus (VARC) in Newport News, Virginia.

The Aeronautics Graduate Research Program commenced in 1971, with the primary goal of engaging students who qualified for regular admission to the Graduate School of Engineering at Old Dominion University in a graduate engineering research and study program in collaboration with NASA Langley Research Center, Hampton, Virginia. Research participants were enrolled in the program for two calendar years. During this period, students were provided a stipend and tuition expenses under a research and study grant from NASA Langley Research Center. Students with diverse baccalaureate preparation in both mathematics and engineering were attracted to the program with the intent of immersing themselves in a study effort and project work at Langley Research Center in aeronautics-related subject matter. The principal investigator had the responsibility to solicit nationally for program

candidates possessing qualifications to enter the graduate engineering departments. Program participants with aeronautics interests were usually selected on the Master's degree level, although several participants, who were highly recommended, entered the program at the Ph.D. degree level. The majority of the Master's students had little difficulty completing all of the requirements, including a thesis, within the two-year tenure. Understanding the program's limited time frame, Ph.D. students and their advisors usually made further arrangements for continuation and degree completion.

Format and Purposes

The first year was essentially used for full-time study, although the principal investigator sought placement of a student in an appropriate branch at NASA Langley Research Center as soon as the student began the program. Participating NASA branch Engineers suggested several projects of interest as students made initial visits, while the student and his guidance committee then decided upon a topic of mutual interest. The second year was designated for full-time research except for an occasional course which may have been taken to support thesis research or otherwise satisfy degree requirements. During the two summers that were a part of the time commitment, the participants were engaged in full-time research at NASA Langley Research Center. Graduate participants satisfied course requirements by attending lectures at the VARC campus, Newport News, and at the main campus in Norfolk; they also met the thesis requirement of the Old Dominion University graduate engineering programs.

The primary purpose of the Aeronautics Graduate Research program was to engage qualified graduate students in a professional research/design experience while simultaneously providing the academic environment for full time

study. In the early days, the cooperative program was administered from the graduate campus in Newport News, Virginia. Research participants found study space, library resources, faculty advisement, and most graduate instruction at the Virginia Associated Research Campus (VARC). At the same time, participants found strong research interaction among themselves and faculty advisors and NASA research engineers. Objectives of the program, defined to serve the interests of selected graduate students, the graduate engineering departments at Old Dominion University, and the aeronautics research interests at NASA Langley Research Center, were successfully met in a number of ways.

How Objectives Were Met

In terms of program administration and the technical assistance which had been provided, it was most gratifying that NASA Langley Research Center engineers and their first line management had found the cooperative program appropriate for and consistent with their needs. A good measure of that level of satisfaction was the ease with which the principal investigator could identify several times more projects and job slots at NASA Langley Research Center that needed research assistants, than there were enrolled program participants. Top management at NASA Langley Research Center took satisfaction in knowing that a supported program, although small in people and dollars, produced qualified engineers for selected aeronautics specialties. NASA gained needed technical assistance for projects, and the culmination was an injection of additional expertise into the aeronautics industry. The Old Dominion University School of Engineering was pleased with the program because it complemented the basic mission of graduate engineering education, combining students, faculty, and practitioners of engineering in a productive, learning environment. The opportunity attracted worthy

students to a program which then assisted in broadening the base of faculty research. Lastly, from the student point of view, a graduate and professional level experience was gained. The full-time program participants took leave of the closed society of graduate student peers in order to be engaged in an actual engineering research and design environment. They traded peers in the traditional sense for a realistic communications experience involving academic engineers (the faculty), NASA engineers and technicians, and the administrators of the program. Of course, their expenses were payed as they were being encouraged to complete a graduate engineering degree. Graduate research participants, who completed degree requirements, were in an excellent job-seeking position.

A joint venture in graduate engineering education is described in this report in terms of the successes and problems which were experienced in a cooperative program of significant duration. The following sections of this final report will cover areas such as student selection and supervision, statistical information concerning the graduate participants, research accomplishments, and the financial arrangement of the program.

GRADUATE PARTICIPANTS AND RESEARCH SUPERVISION

This chapter provides pertinent data about the origins and progress of the research participants. The first section covers student selection and advisement followed by the statistical data.

Student Selection and Advisement

Students were solicited on a nationwide basis with the main requirements being that candidates had met graduate school admission requirements, had a B.S. in Science or Engineering, and had indicated an interest in graduate study with an aeronautics emphasis. Candidates for the program must have displayed not only acceptable academic credentials, but also behavioral traits that indicated a potential for interacting productively with a variety of advisors and peers, and must have showed poise and self-starting capabilities. Solicitation for applicants was conducted each year in the winter for candidates who were prepared to enter the two-year program in the Fall. By April, awards were made and two-year commitments were promised. Awardees were selected by the principal investigator, originally at the Virginia Associated Research Campus (VARC), in consultation with the appropriate departmental graduate program directors. Aeronautics research students were then enrolled in a department consistent with their background and interest. After being immediately introduced to engineers in several branches at NASA/Langley Research Center through contacts made by graduate faculty and the program principal investigator, each new participant began spending a limited amount of time in the NASA laboratories under the supervision of a NASA engineer, who became a co-chairman of the student's guidance committee. Concurrently, a faculty member was found who would take an interest in the student's topical area for research and study, and was

designated as guidance committee co-chairman. The guidance and evaluation committee was formally appointed by the participant's departmental chairman and had at least three members, a majority of whom were Old Dominion University faculty members. Faculty advisors became more or less involved with the student research project, but the faculty committee co-chairman was chosen in order to bring some expertise to the work of the NASA branch where the research participant was engaged. The faculty guidance committee co-chairman was responsible to the academic department chairman to determine that the research participants completed all degree requirements. The NASA Advisor was very instrumental in the research/design project planning, and was also a full participant in the evaluation of student progress. When appropriate, NASA advisors were offered research appointments in the School of Engineering. Table 1 is included in order to recognize each graduate student's faculty advisor with his associated university engineering department, and each participating NASA advisor and his associated branch. The names of program participants are listed chronologically (see also Table 2). Joint advisement was an important element of the program enabling successful completion of research tasks and degree requirements.

Essential features in selecting candidates were the "quality" of the applicants and the competition over the years for the relatively few talented graduate students interested in aeronautics. Competition was keen for requisite applicants; it seemed to be increasingly difficult to lure baccalaureate graduates into full-time graduate study, even with a competitive stipend. It was the main problem associated with the administration of the grant program, the securing of highly qualified graduate students necessary to make the program a success academically. Also, it was important to find technically able people for the NASA branches who desired the aid of

Table 1. Research Participants and Their Faculty and NASA Advisors

Name	Dept.	ODU Advisor	NASA Branch	NASA Advisor
John Carr	EE	Dr. G. J. McRee	Flight Instrumentation Division	William E. Howell
Joan P. Gosink	MEM	Dr. G. L. Goglia	Computational Methods Branch	Dr. Julius E. Harris
Joanne L. Walsh	MATH	Dr. J. Heinbockel	Structural Mechanics Branch	Dr. W. J. Stroud
Leroy F. Albang	MEM	Dr. S. Tiwari	Analytical Methods Branch	Richard Margason
Garla Arjuna	CE	Dr. Ken Murray	Structural Mechanics Branch	Dr. James H. Starnes
Michael Berger	MEM	Dr. S. Tiwari	Viscous Flow Branch	I. E. Beckwith
Phillip Drummond	MEM	Dr. R. L. Ash	Hypersonic Aerodynamics Branch	Mr. Bob Jones
Joseph T. Fuss	MEM	Dr. J. Breedlove	Aerosol Research Branch	Jose M. Alvarez
Raymond Chapman	CE	Dr. C. Kuo	Marine Environment Branch	Dr. Charles Whitlock
Richard Hart	MEM	Dr. J. Kuhlman	Fluid Dynamics Branch	Jerry Adcock
S. Venkatasubramanian	MEM	Dr. S. Tiwari	Chemistry and Dynamics Branch	Dr. H. Reichle
Mark Pardue	EE	Dr. J. Stoughton	Stability and Control Branch	Dr. W. W. Anderson
Charles Marshall	EE	Dr. Varanasi	Navigation & Guidance Research Branch	David R. Downing
Arun A. Nadkarni	MEM	Dr. J. Breedlove	Stability and Control Branch	Dr. W. W. Anderson Nelson Groom
Paul Nystrom	MEM	Dr. A. S. Roberts	Aerocoustics Branch	Dr. J. M. Seiner
Sophia K. Ashley	MEM	Dr. J. Kuhlman	Fluid Dynamics Branch	Ed Polhamus

Table 1. Research Participants and Their Faculty and NASA Advisors (Continued)

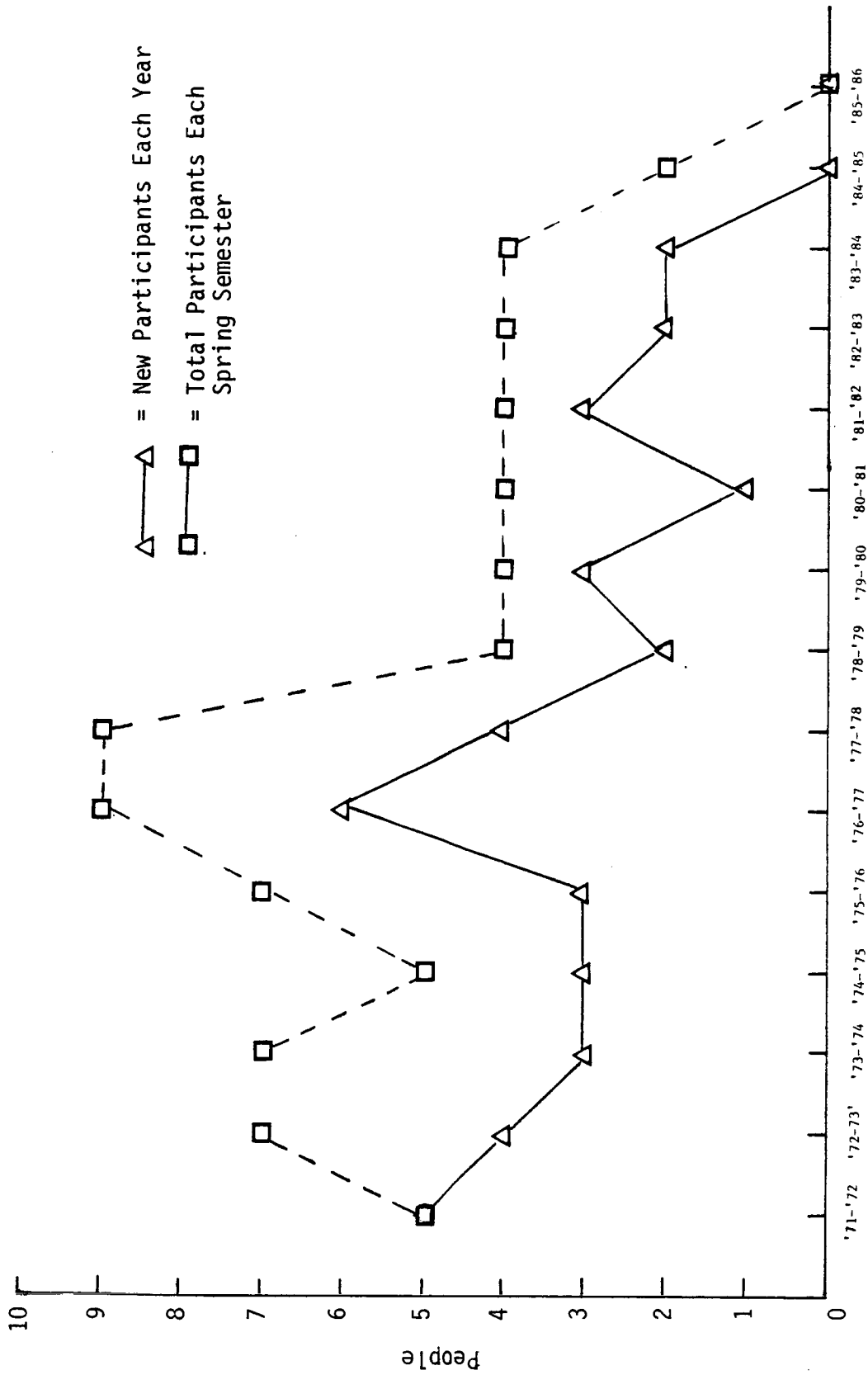
Name	Dept.	ODU Advisor	NASA Branch	NASA Advisor
David Livingston	EE	Dr. M. Varanasi	Simulation and Human Factors Branch	Mr. Patrick Gaines
Phillip Mastic	EE	Dr. P. B. Johnson	Navigation and Guidance Research Branch	Carroll Lytle
Woodrow Wagner	MEM	Dr. J. Kuhlman	Materials Application Branch	Dr. Howard Price
Stephen Wilkinson	MEM	Dr. R. L. Ash	Fluid Mechanics Branch	Dr. Leonard Weinstein
Louis Roussos	MEM	Dr. E. Thornton	Structural Mechanics Branch	Dr. E. T. Kruszewski
Tommy Augustsson	MEM	Dr. S. Tiwari	Atmospheric Science Branch	Dr. Joel Levine
Thomas Johnson	MEM	Dr. Rao	Fluid Dynamics Branch	Dr. Jim Campbell
Michael Lazar	MEM	Dr. A. Nadkarni	Theoretical Mechanics Branch	Walt Oehman
Gilbert Kraemer	MEM	Dr. S. Tiwari	Hypersonic Propulsion Branch	Dr. Clay Rogers
Ime I. Akpan	MEM	Dr. A. S. Roberts	Spacecraft Controls Branch	Dr. R. C. Montgomery
Raymond Wall	MEM	Dr. R. L. Ash	Electro-Mechanical Instrumentation Branch	Dr. P. Tcheng
Barry S. Spigel	MEM	Dr. R. Prabhakaran	Thermal Structures Branch	Dr. James Sawyer
Ajit Kelkar	MEM	Dr. R. Prabhakaran	Fatigue and Fracture Branch	Dr. W. Elber
Kevin Oakes	MEM	Dr. C. Mei	Structural Dynamics Branch	Dr. J. M. Housner
Rajiv Naik	MEM	Dr. R. Prabhakaran	Fatigue and Fracture Branch	Dr. J. H. Crews, Jr.

qualified research assistants.

A promotional mailing was conducted annually and was directed to chair persons of engineering departments around the country in the disciplinary areas of mechanical, electrical, civil, aeronautical engineering and engineering mechanics. The purpose was to attract the most able applicants to the graduate engineering research participation program in aeronautics. The program administrator found in conversations with other aero-related program administrators around the country that the pool of qualified students who would enter full-time graduate study with an aeronautics emphasis was small, relative to the number of graduate programs competing for these persons. The recruiting results, treated in more detail in a later section, demonstrates the difficulty experienced in securing student participants best suited for the program, a problem likely to continue in the competitive market for young engineering talent.

Program Statistics

During the 15 year tenure of the Aeronautics Research Participation Program, a total of 41 graduate students were enrolled at one time or another. Since students entered the program on different calendar dates and finished their research assignments at their own pace, coordinating with their faculty and NASA advisors, the number of active program participants changed throughout each academic year. The aggregate of program participants each spring semester is illustrated in Figure 1. The graph also, shows the number of new awardees enrolled each academic year. In order to maintain a "steady state" count in the program, new participants were accepted as needed and as funding was available. After an annual recruiting campaign (starting in 1974-75) by the principal investigator, offers were made and positions were accepted by promising candidates. Figure 2,



Calendar Year
June through May

Figure 1. Program Enrollment Data.

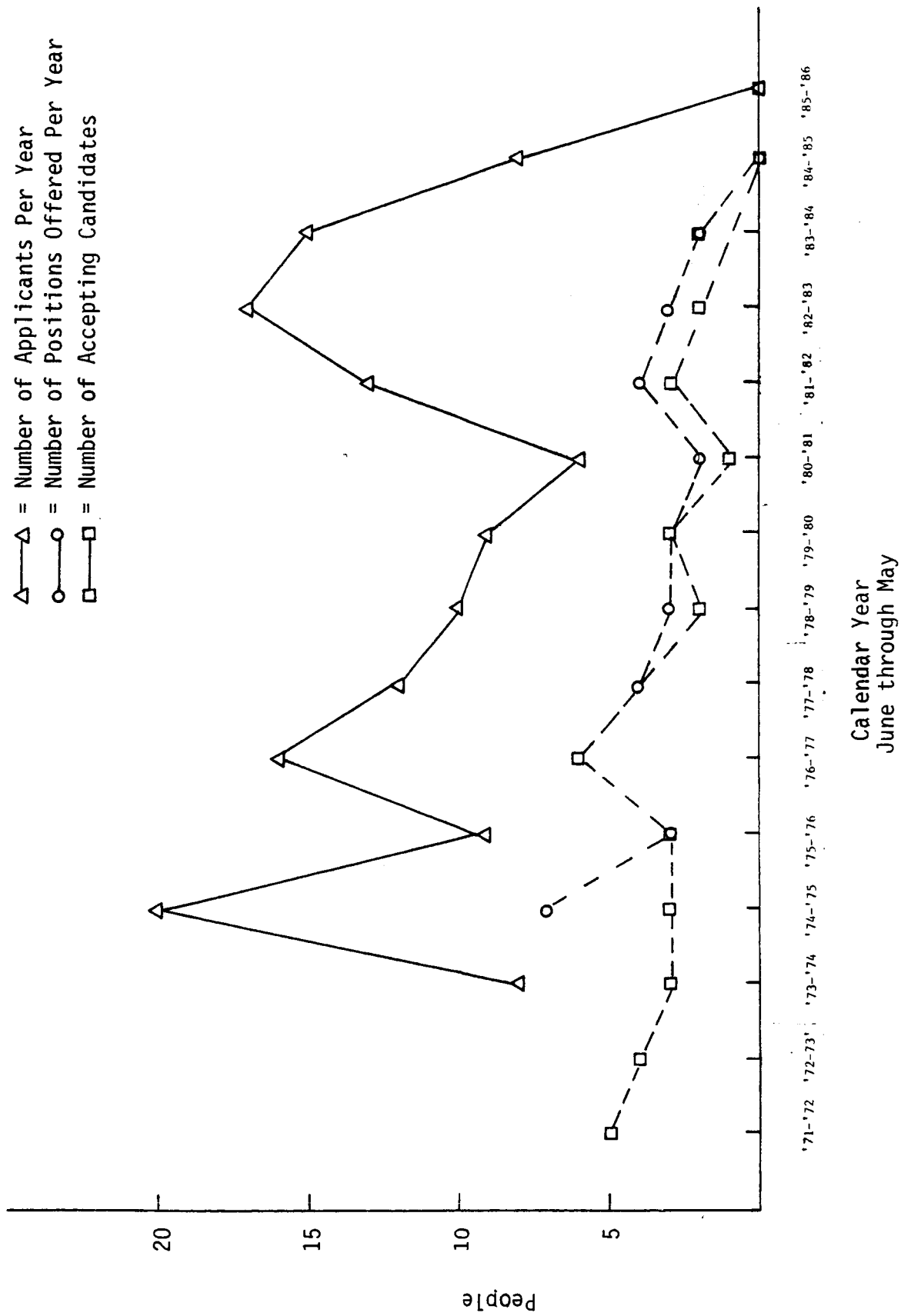


Figure 2. Research Participant Recruiting Results.

displays the total number of applicants, the total number of positions offered, and the total number of acceptances for each recruiting period. As seen on the graph (of Figure 2), the academic year 1974-75 seemed to be the peak year for applicants and offered positions, being 20 and 7 respectively. A total of six accepting awardees entered during the academic year 1976-77, the largest contingent of research participants to enter at one time.

Of the 41 program participants, 3 were women and 38 were men. All three women, Sophia Ashley, Joanne Walsh, and Joan Gosink, received a Masters of Engineering in the two-year time period of the program. The program administration was pleased to hear that Ms. Sophia Ashley received a 1985 Federal Engineer of the Year Award. Ms. Ashley was of Greek origin but maintained a USA citizenship. There were seven foreign nationals who participated in the graduate aeronautics research program: five Indians, one Nigerian, and one Swede. The remaining 33 participants were of USA citizenship, although several of those had foreign origins. The program director attempted to recruit such candidates as women, minority group USA citizens; and, secondarily, foreign nationals for the cooperative aeronautics research participation program.

The contrasting backgrounds of the program participants contributed to a wide range of academic achievement among the graduates. The participants' undergraduate degrees ranged from Bachelors of Science in mechanical, electrical, aeronautical, and nuclear engineering to Bachelors of Science in physics, mathematics, and geology. Only sixteen out of the 41 overall enrollees earned undergraduate degrees from Old Dominion University. In part measure this was the result of an effort by the program director to bring in qualified graduate students from outside eastern Virginia.

Principal products of the program were the student graduates who

completed their advanced degrees working between the University and NASA/Langley Research Center, and then moved on into engineering practice. During the active years of the program, thirty-one program participants completed their graduate degrees; 26 of these were at the masters level and 5 at the doctoral level. These persons and their thesis titles are listed in Table 2. This table is an accumulative record of all graduates of the aeronautics research participation program. Items also listed in Table 2 are academic accomplishments, academic year of program completion, and the specific department and the type of degree earned. As a visual reference, Figure 3 depicts the number of program graduates for each academic year. Happening in both 1974-75 and 1978-79, the largest contingent of graduates to finish in the same academic year was five. In contrast the years 1975-76 and 1981-82 show no production of graduates from the aeronautics program.

Dan Stead, a former participant in the aeronautics program, is expected to complete his thesis and graduate during the academic year 1986-87 at ODU. Mr. Stead was unable to finish degree requirements during the two-year program tenure, but is working successfully to complete research in experimental fluid mechanics. The remaining 9 of the total 41 participants withdrew from the program for either personal reasons or because they failed to meet program requirements. The number of awardees who failed to meet standard requirements other than personal reasons was only 3. These graduate participants were asked to resign after sufficient warning that their program success was in danger. The final 6 withdrew for various personal reasons, usually early in the program. The principal investigator tried to fill those participant vacancies by the beginning of the next semester. In summary 31 people graduated with full or partial support from the grant program, 1 student is continuing with graduation in sight, and 9

Table 2. Cumulative list of graduates under NASA grant NGR 47-003-052.

Name	Degree, Depart., College, Grad. Date	Acad. Yr. of Completion	Department	Degree	Thesis Title
John E. Carr	BS Electrical Engin. ODU June 1969	1971-72	Electrical	ME*	None
Joan P. Gosink	BS Mathematics MIT Jan. 1962	1972-73	Mech. Eng. & Mechanics	ME	Numerical Study of the Turbulent Boundary Layer in a Hypersonic Nozzle
Joanne L. Walsh	BA Mathematics ODU June 1971	1973-74	Mech. Eng. & Mechanics	ME	Computer-Aided Design of Light Aircraft to Meet Certain Aerodynamic and Structural Requirements
Leroy F. Albang	BS Aeronautical Engin. Iowa State 1972	1974-75	Mech. Eng. & Mechanics	ME	Analysis of Spread Multi-Jet VTOL Aircraft in Hover
Garla Arjuna	BS Mechanical Engin. Anantapur, India June 1969	1974-75	Mech. Eng. & Mechanics	ME	The Effect of Unreinforced Cutouts on the Buckling of Thin Conical Shells Loaded by Central Axial Compression
Michael H. Berger	BS Mechanical Engin. ODU June 1972	1974-75	Mech. Eng. & Mechanics	ME	Application of Boundary Layer Theory to Suction Through Streamwise Slots in Wind Tunnel Walls
J. Phillip Drummond	BS Nuclear Engin. UVA June 1970	1974-75	Mech. Eng.	ME	A Method for Improving the Accuracy in Phase Change Heat Transfer Data Through Increased Precision in Thermophysical Property Determination

(cont'd)

Table 2. (Continued)

Name	Undergraduate College	Acad. Yr. of Completion	Department	Degree	Thesis Title
Joseph T. Fuss	BS Aeronautical & Mechan. Engin. Rose-Hulman May 1972	1974-75	Mech. Eng. & Mechanics	ME	Dynamics of Explosion Remnants in Earth Orbits
Raymond S. Chapman	BS Geology ODU May 1975	1976-77	Civil	ME	A Model to Investigate the Influence of Suspended Sediment on the Mass Transport of a Pollutant in Open Channel Flow
Richard C. Haut, II	BS Mechanical Engin. Rose-Hulman May 1974 MS Aerospace Engin. Univ. of Tennessee Aug. 1975	1976-77	Mech. Eng. & Mechanics	Ph.D.	Evaluation of Hydrogen as Cryogenic Wind Tunnel Test Gas
S.V.S. Manian	BE Mechanical Engin. Madras Eng. College, India July 1972	1976-77	Mech. Eng. & Mechanics	ME	Evaluation of Upwelling Infrared Radiance in a Nonhomogeneous Nonequilibrium Atmosphere
Mark D. Pardue	BS Electrical Engin. ODU May 1975	1976-77	Electrical	ME	Automatic Stabilization of Helicopter Sling Loads by Reaction Jets
Charles C. Marshall	BS Electrical Engin. ODU May 1975	1977-78	Electrical	ME	A Comparison of Digital Computers in Implementing Avionic Control Laws
Arun A. Nadkarni	BE Mechanical Engin. Bangalore Univ. India June 1966 ME Aeronautical Engin. Indian Institute of Science Aug. '68 MS Aerospace Engin. Penn. State Univ. Aug. '73	1977-78	Mech. Eng. & Mechanics	Ph.D	Optimal Control of a Large Space Telescope Using an Annular Momentum Control Device

(cont'd)

Table 2. (Continued)

Name	Undergraduate College	Acad. Yr. of Completion	Department	Degree	Thesis Title
Paul A. Nystrom	BS Mathematics Rose-Hulman March '74	1977-78	Mech. Eng. & Mechanics	ME	Static Temperature Measurements in Supersonic Flow Using Laser Raman Spectroscopy
Sophia K. Ashley	BS Physics June '65 MS Physics June '68 NE Louisiana State Univ.	1978-79	Mech. Eng. & Mechanics	ME	Inviscid Two-Dimensional Vortex-Panel Method for Calculating the Pressure Distribution Over Non-circular Cylinders at Various Flow-Incident Angles
David L. Livingston	BS Electrical Engin. ODU Dec. '76	1978-79	Electrical	ME	A High-Speed Algorithmic Signal Processor
Phillip S. Mastic	BS Aerospace Technology Kent State Dec. '71	1978-79	Electrical	ME	Second Order Open Loop Omega Phase Detector: Microprocessor-Based
Woodrow W. Wagner	BS Industrial Engin. and Operational Research VPI & SU June '71	1978-79	Mech. Eng.	ME	Temperature and Time Dependent Viscosity of Elastomer Modified Epoxy Resin
Stephen P. Wilkinson	BS Thermal Engin. ODU Jan. '71	1978-79	Mech. Eng. & Mechanics	ME	An Experimental Investigation of a Turbulent Boundary Layer with Suction Through Closely Spaced Streamwise Slots
					(cont'd)

Table 2. (Concluded)

Name	Undergraduate College	Acad. Yr. of Completion	Department	Degree	Thesis Title
Louis A. Roussos	BS Mechanical Engin. ODU May '77	1979-80	Mech. Eng. & Mechanics	ME	Finite Element Model of Timoshenko Beam with Structural Damping
Tommy T. Augustsson	BS Aerospace Engin. U. of Florida June '65 MS Atmospheric Science G. Washington Univ.	1980-81	Mech. Eng. & Mechanics	Ph.D.	Effects of Multiple Scattering and Surface Albedo on the Photochemistry of the Troposphere
Thomas D. Johnson, Jr.	BS Electrical Engin. Air Force Inst. of Tech. June '68	1980-81	Mech. Eng.	ME	Experimental Study of Delta Wing Leading-Edge Devices for Drag Reduction at High Lift
Michael P. Lazar	BS Aerospace Eng. Penn. State Dec. '72	1980-81	Mech. Eng. & Mechanics	ME	Low Speed Handling Characteristics of a Supersonic Transport by Eigenstructure Assignment
Gilbert O. Kraemer	BS Mechanical Engin. ODU	1982-83	Mech. Eng. & Mechanics	ME	Interaction of a Two-Dimensional Transverse Jet in a Supersonic Mainstream
Ime I. Akpan	BS Mechanical Engin. Boston Univ. May '80	1982-83	Mech. Eng. & Mechanics	ME	An Approach for Including Reliability in Control System Designs
Raymond H. Wall	BS Mechanical Engin. ODU Aug '81	1983-84	Mech. Eng. & Mechanics	ME	The Development of a Micro-Processor Controlled Linearly Actuated Valve Assembly
Barry S. Spiegel	BS Engineering Science and Mechanics VPI & SU Dec '80	1984-85	Mech. Eng. & Mechanics	ME	An Experimental and Analytical Investigation of the Iosipescu Shear Test for Composite Materials

*ME - "Master of Engineering" in respective department.

Table 2. Program Graduates under NASA grant NGR 47-003-052

Name	Undergraduate degree, Dept., School	Acad. Yr. of Program Completion	Department	Degree Earned	Thesis Title
Ajit Kelkar	BS Mech. Engrg. College of Engrg., India - May 1975 MS Mechanical Engrg. South Dakota State University, May 1981	1985-86	Mechanical Eng. and Mechanics	Ph.D.	Prediction of Residual Tensile Strength of Transversely Impacted Composite Laminates
Kevin Oakes	BS Mechanical Engrg. ODU, Dec. 1983	1985-86	Mechanical Eng. and Mechanics	ME	Dynamic Analysis of an Earth-Orbiting Satellite Deploying Hinged Appendages
Rajiv Naik	B. Tech., I.I.T, Bombay, India, June 1979 MS Mechanical Engrg. U. of Maine, May, 1982	1986-87	Mechanical Eng. and Mechanics	Ph.D.	An Analytical and Experimental Study of Clearance and Bearing-By-pass Load Effects in Composite Bolted Joints

*ME - "Master of Engineering" in respective department.

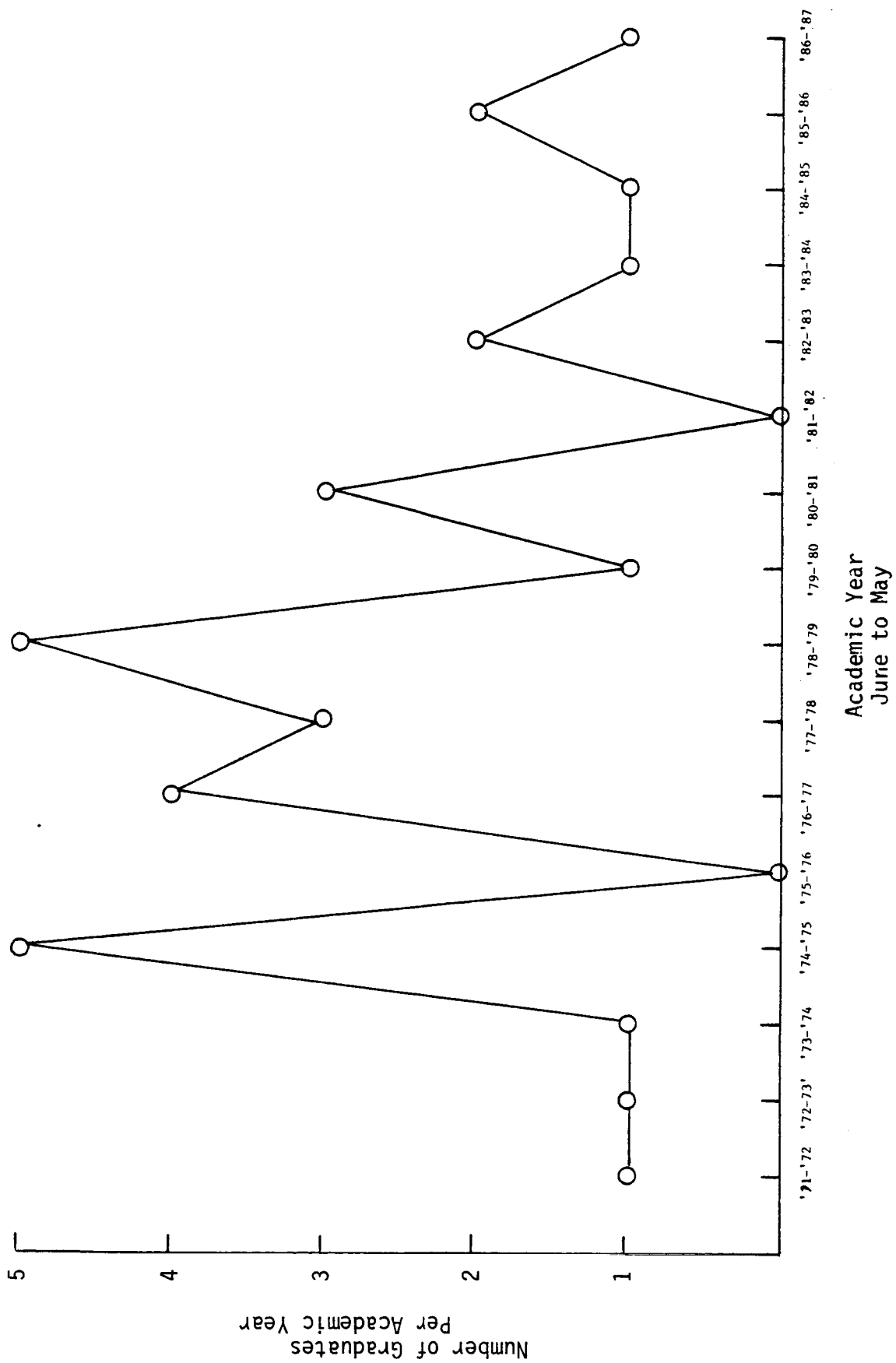


Figure 3. Number of Graduates Per Academic Year.

participants dropped out of the program -- Totaling 41 graduate participants.

Insofar as data is complete at this time, Table 3 displays the initial occupational status of thirteen of the program graduates. Many of these jobs were entered directly after graduation, therefore they may be inaccurate for the present. One object of the grant program was to contribute graduates to the national pool of engineers qualified and interested in aeronautics-related practice. As is seen from Table 3, all but 4 of the 13 graduates are engaged in some form of aeronautics activity. To the extent shown, the Aeronautics Research Participation Program has gained a rung of its original objective. It is also interesting to note that 4 of the graduates listed in Table 3 gained employment at NASA Langley Research Center.

Table 3. Occupational Status of Program Graduates

Name		Status	Aeronautics Related Employment
Joanne Walsh	(ME)	NASA-LRC	Yes
Michael Berger	(ME)	Oak Ridge National Laboratory, Oak Ridge, Tenn.	No
Phillip Drummond	(ME)	NASA-LRC	Yes
Richard Haut	(Ph.D)	Exxon Research Houston, Texas	No
Arun Nadkarni	(Ph.D)	Boeing Company	Yes
Sophia Ashley	(ME)	Naval Engineering Command, Port Hueneme, CA	No
David Livingston	(ME)	IBM	No
Stephen Wilkinson	(ME)	NASA-LRC	Yes
Louis Roussos	(ME)	NASA-LRC	Yes
Gilbert Kraemer	(ME)	Combustion Engineering, Conn.	Yes
Raymond Wall	(ME)	Fort Eustis, Virginia	Yes
Barry Spigel	(ME)	Fort Eustis, Virginia	Yes
Ajit Kelkar	(Ph.D)	North Carolina A and T University, Greensboro, N.C.	Yes

RESEARCH ACCOMPLISHMENTS

Grant funds were allocated for Aeronautics research. The principal investigator sought to achieve this objective, but in doing so found that the final research product would be determined by (1) the needs of companion NASA/LaRC Branches, (2) the already developed directions of faculty research, and (3) the capabilities and interests of the graduate research participants. The direct research results are the thirty (30) theses and several papers, published and presented, which were produced. However, the graduate research assistants accomplished in many cases additional and peripheral tasks for the NASA hosts, as well as assisting faculty advisers toward expanding their research programs. At least the direct research results can be recorded here.

While the objective was to produce aeronautical research results, while educating graduate students, and the majority of the theses fall in this area, other topics were occasionally treated, based on an appropriate match of interests between students and their advisers. The three broad research areas were aeronautics, aerospace, and environmental engineering. Specific research results were achieved in the following categories (number of theses in parenthesis):

1. Aircraft Design, Aerodynamics, Lift/Drag Characteristics
(3)
2. Avionics: Aircraft Guidance and Control (3)
3. Fluid Mechanics: Inviscid flow, Boundary Layer and
Gas Dynamic Studies (6)
4. Solid Mechanics: Composites, Shells, Beams Under Static,
Impact and Transient Loading (5)
5. Instrumentation and Measurement Techniques (4)

6. Thermophysical Properties Experiments (12)
7. Large Space Structures: Dynamics, Control, Reliability Analysis (2)
8. Earth Orbital Dynamics (2)
9. Environmental Engineering: Water Quality Modeling and Atmospheric Radiation Processes (3)

The aeronautics related categories extend through number 6. above, incorporating 23 out of the 30 graduate theses which were produced. A statement of the objectives, methods and main results for each of the research tasks is contained in the theses abstracts which are included as Appendix A of this report. The theses are referenceable documents housed in the Old Dominion University Library.

A number of technical papers were published and presented as a result of the work accomplished under the grant. Those papers known to the principal investigator, and specifically involving the research participants, are listed as Appendix B. The research participants' name is underlined in each citation. There were probably additional documented works which did not come to the principal investigator's attention.

BUDGETARY SUMMARY

Funds were expended over a period of fifteen years to accomplish grant program objectives. In fact the original grant award carries a date of September 1, 1971. It is well to note this was a "non-specific" research grant in contrast to the traditional unsolicited proposals and grant mechanism for research awards. Of course, in the case of the subject grant, there was a strong graduate education component coupled with the research objectives; and, a larger than usual fraction of total grant funds was earmarked for graduate research participant stipends.

Stipends paid to research participants amounted to 63% of total, aggregate direct cost or 56% of total direct plus indirect costs. These aggregate amounts are,

Total direct costs	\$742,390
Total indirect costs	<u>96,532</u>
Total expenditure	\$838,922

Another way to view the cost of the program is in terms of the number of research participants who graduated, the degrees produced. Since Ph.D. students and Masters students all were supported for a nominal two-year tenure in the program, there is no differentiation of costs on the basis of degree level. For thirty-one (31) program graduates, the costs per advanced engineering degree are,

Cost per degree, direct	\$24,000
Cost per degree, direct plus indirect	\$27,000

The above costs were rounded to the nearest thousand dollars. Certainly on the basis of current dollars, this is graduate engineering education at bargain prices[†].

[†]It was occasionally necessary to support by other means some students beyond their two-year tenure in the program. Those costs are rolled into in the above estimates.

Finally, to document in more detail how the grant funds were expended, Table 4 shows current, aggregated budget status for the main categories of expenditures.

Table 4. Record of Budgeted Expenditures

<u>Description</u>	<u>Amount</u>
1. Salaries and Wages	
Principal Investigator	143,053.00
Graduate Students	467,218.00
Faculty/Research Associates	<u>27,616.00</u>
Subtotal	637,887.00
2. Fringe Benefits	47,411.00
3. Supplies (office/lab)	9,440.00
4. General Expenses	
Tuition	28,585.00
Publications/subscriptions/report preparation	2,925.00
Computer charges	<u>1,553.00</u>
Subtotal	33,063.00
5. Travel	14,194.00
6. Equipment	<u>395.00</u>
Total Direct Costs	742,390.00
Total Indirect Costs	<u>96,532.00</u>
Total Expenditure	\$838,922.00

APPENDIX A

Thesis Abstracts Arranged by the Nine Subject Area Categories

1. Aircraft Design,
Lift and Drag
Characteristics

ABSTRACT

EXPERIMENTAL STUDY OF DELTA WING LEADING-EDGE DEVICES FOR DRAG REDUCTION AT HIGH LIFT

Thomas Dwight Johnson, Jr.
Old Dominion University, 1980
ODU Director: A. Sidney Roberts, Jr.
NASA Director: Dr. Jim Campbell

Future fighter aircraft requirements specify efficient supersonic cruise and high-g maneuverability at high lift. The slender delta wing meets the first requirement but has large lift induced drag increments at high lift. One method to alleviate the drag is to control the flow at the wing leading edge (LE) by means of small LE devices, so as to maintain locally attached flow to higher angles of attack and thus increase the level of aerodynamic thrust.

The devices selected for evaluation were the fence, slot, pylon-type vortex generator (VG), and sharp leading-edge extension (SLEE). These devices were tested on a 60° flatplate delta (with blunt LE) in the Langley Research Center (NASA) 7- by 10-foot high-speed tunnel at low-speed and to angles of attack of 28°. Balance and static pressure measurements were taken.

The results indicate that all the devices had significant drag reduction capability and improved longitudinal stability while a slight loss of lift and increased cruise drag occurred.

ABSTRACT

ANALYSIS OF SPREAD MULTI-JET VTOL AIRCRAFT IN HOVER

Leroy F. Albang
Old Dominion University, 1980
ODU Director: Dr. Tiwari
NASA Director: Richard J. Margason

An investigation of vertical takeoff and landing (VTOL) aircraft lift losses in hover has been conducted to evaluate a method for a simplified test technique.

Three flat plate models were tested to determine their usefulness in predicting hover characteristics by comparing results between plate and three-dimensional models. Attempts to correlate the out of ground effect results for the plate models with the empirical expression for calculating jet induced loads were successful for the models which used engine simulators producing efflux characteristics similar to the three-dimensional model engines. Data for the model using engine simulators with characteristics unlike those of the three-dimensional model simulators could not be correlated in this manner.

In ground effect, comparisons of induced lift loads indicated correlations between the plate and three-dimensional models were within 2 percent of thrust in the height range dominated by the fountain effect. However, small outward deflection of the lift engine exhaust was found to cause a decrease in beneficial fountain on the order of 5 to 10 percent of thrust. Dashpots proved useful in eliminating data scatter caused by flow-induced model vibration. The engine arrangement of a midspan-pod VTOL lift-fan transport model showed a strong adverse effect on lift loss due to engine deflection. Data obtained for the plate models could be correlated to three-dimensional results by the application of a geometrical equivalent

height correction factor $\Delta H D_e$. The correlation of plate and tunnel models indicated that lift losses in ground effect were essentially independent of the efflux characteristics for the engine simulators.

ABSTRACT

COMPUTER-AIDED DESIGN OF LIGHT AIRCRAFT TO MEET CERTAIN AERODYNAMIC AND STRUCTURAL REQUIREMENTS

Joanne Lynn Walsh
Old Dominion University
ODU Director: Dr. John H. Heinbockel
NASA Director: W. Jefferson Stroud

Nonlinear mathematical programming techniques are applied to a particular aircraft design problem, that of determining the maximum range design for light aircraft subject to certain aerodynamic and structural requirements. Search techniques available in an existing nonlinear optimization computer program, AESOP, are applied to the design problem. Seven design variables are used to define the wing dimensions, the wing skin thickness, the cruise velocity, the amount of fuel carried, and the engine horsepower. The influence of different design requirements on the range is observed and discussed.

2. Avionics:
Guidance and Control

ABSTRACT

STABILITY AND CONTROL OF A SLING LOAD USING ACTIVE JETS

Mark D. Pardue
Old Dominion University, 1977
ODU Director: Dr. John W. Stoughton
NASA Director: Dr. Shaughnessy

Helicopter sling load work has been increasing over the past decade, and accidents have resulted due to loss of control of the helicopter or collision with objects. It is desired to dampen swinging of the sling load and thus reduce pilot workload and pilot error. This would have a positive effect on accident reduction.

An active jets control system was designed using velocity feedback. Values of feedback gain are presented in graphs for various loads, helicopters, and single-cable suspension systems. Damping ratios of 0.7 for a wide range of parameters are verified by implementation on a helicopter sling load simulation.

ABSTRACT

LOW SPEED HANDLING CHARACTERISTICS OF A SUPERSONIC TRANSPORT BY EIGENSTRUCTURE ASSIGNMENT

Michael Peter Lazar
Old Dominion University, 1981
ODU Director: A. Nadkarni
NASA Director: Walt Oehman

A synthesis procedure, based upon optimal regulator theory and eigenvalue/eigenvector assignment technique, was used in the design of a low-speed lateral control system for the SCAT-15F supersonic transport. Emphasis was placed on reducing the lateral acceleration at the pilot's station. Control laws were designed to make the aircraft handling characteristics acceptable with the exception of the lateral acceleration. It was found that a compromise between the roll performance requirements and the peak lateral acceleration requirement is needed for a successful SCAT-15F design.

ABSTRACT

A COMPARISON OF DIGITAL COMPUTERS IN IMPLEMENTING AVIONIC CONTROL LAWS

Charles C. Marshall
Old Dominion University, 1977
ODU Director: Dr. Muralidhara Varanasi
NASA Director: David R. Downing

Direct digital control laws impose definite processing requirements upon the digital computer. A computer's ability to perform these requirements at a minimum life-cycle cost should be evaluated prior to its acquisition. The possibility of using several microprocessors in a multi-computer organization to replace a single minicomputer is attractive only if it is cost effective; thus the actual life-cycle cost incurred in each instance must also be evaluated. Because of the many interacting effects of the possible configurations of a computer system a straightforward evaluation is not feasible. This thesis develops an evaluative tool which accounts for these interacting effects. The CPU execution time of one iteration of the control law and the affected life cycle costs are combined into a figure of merit which can be used to evaluate the relative ability and costs of candidate computers. Results indicate that a multicomputer organization of microprocessors can perform as well as a single minicomputer at one-third the cost.

3. Fluid Mechanics: Inviscid, Boundary Layer and Gas Dynamics Studies

ABSTRACT

AN EXPERIMENTAL INVESTIGATION OF A TURBULENT BOUNDARY LAYER WITH SUCTION THROUGH CLOSELY SPACED STREAMWISE SLOTS

Stephen P. Wilkinson
Old Dominion University, 1978
ODU Director: Dr. Robert Ash
NASA Director: Leonard Weinstein

The object of this research was to experimentally evaluate a suction surface for use with incompressible turbulent boundary layers. The surface consisted of an array of closely spaced slots aligned in the direction of the free-stream flow. Direct drag and mean boundary-layer velocity profile measurements showed that the slotted surface had nominally the same suction characteristics as a porous surface.

ABSTRACT

APPLICATION OF BOUNDARY LAYER THEORY TO SUCTION THROUGH STREAMWISE SLOTS IN WIND TUNNEL WALLS

Michael H. Berger
Old Dominion University, 1974
ODU Director: S. N. Tiwari
NASA Director: I. E. Beckwith

A theoretical investigation at Mach 6 and 8 has been conducted on a model of a wind tunnel sound shield. The flat plate model consists of interchangeable circular and wedge shaped longitudinal rods with gaps between the rods for boundary layer removal. One-dimensional gas dynamics results have been applied to model the pressure distribution for the array of cylinders. Comparisons with experimental pressure distributions and numerical potential flow solutions indicate good agreement. It has been demonstrated that stagnation line heat transfer can be accurately predicted for laminar and turbulent flow for circular cylinders. The flow around the wedge rods was apparently disturbed and hence no truly laminar or turbulent data were obtained. In view of the large effective sweep angle of the circular rods with respect to the local flow (89°), boundary layer behavior was surprisingly well represented by swept cylinder theory. A study of transition data indicates laminar flow was maintained up to a local diameter Reynolds number of 1.5×10^5 which is in agreement with results for isolated swept cylinders. Measurements by NASA - Langley staff indicate considerable noise reductions in the shielded region. Thus the model is apparently a viable sound shield.

ABSTRACT

EVALUATION OF HYDROGEN AS A CRYOGENIC WIND TUNNEL TEST GAS

Richard Carl Haut II
Old Dominion University, 1977
ODU Director: Dr. John Kuhlman
NASA Director: Jerry Adcock

A theoretical analysis of the properties of hydrogen has been made to determine the suitability of hydrogen as a cryogenic wind tunnel test gas. By using cryogenic hydrogen, instead of air or cryogenic nitrogen, as the wind tunnel test gas, a significant increase in test Reynolds number may be achieved without increasing the aerodynamic loads. Under sonic conditions, for example, compared to air at ambient temperature, cryogenic hydrogen at a pressure of one atmosphere produces an increase in Reynolds number of a factor of approximately 14 while cryogenic nitrogen, at the same pressure, produces an increase of only a factor of about 6.

The theoretical saturation boundary for parahydrogen is well defined. Thus, any possible effects caused by the liquefaction of the test gas can easily be avoided by knowing the maximum local Mach number on the model.

The nondimensional ratios used to describe various flow situations in hydrogen were determined and compared with the corresponding ideal diatomic gas ratios. The results were used to examine different inviscid flow configurations. This investigation concluded that the relatively high value of the characteristic rotational temperature causes the behavior of hydrogen, under cryogenic conditions, to deviate substantially from the behavior of an ideal diatomic gas in the compressible flow regime. Therefore, if an ideal diatomic gas is to be modeled, cryogenic hydrogen is unacceptable as a wind tunnel test gas in a compressible flow situation.

However, at low Mach numbers where the assumption of incompressibility

is valid, the deviations in the isentropic flow parameters for cryogenic parahydrogen from the corresponding flow parameters for an ideal diatomic gas are negligible. Thus, in the incompressible flow regime, cryogenic hydrogen is an acceptable test gas.

Hydrogen properties and fan drive-power requirements related to a hydrogen wind tunnel were also examined. The drive-power requirements were found to decrease with decreasing temperature and may be adequately predicted by using modified versions of the ideal gas equations. Since gaseous hydrogen is capable of penetrating and degrading the mechanical characteristics of numerous materials, materials known to be compatible with hydrogen must be used exclusively in the design of a hydrogen wind tunnel to avoid problems as a result of exposure to gaseous hydrogen.

A literature survey resulted in the conclusion that although hydrogen is a highly combustible substance, safety codes exist which, when followed, minimize the risk involved in handling hydrogen.

ABSTRACT

INVISCID TWO-DIMENSIONAL VORTEX-PANEL METHOD FOR CALCULATING THE PRESSURE DISTRIBUTION OVER NONCIRCULAR CYLINDERS AT VARIOUS FLOW INCIDENCE ANGLES

Sophia Kokkinos Ashley
Old Dominion University, 1978
ODU Director: Dr. John M. Kuhlman
NASA Director: Ed Polhamus

A method has been implemented to calculate the potential flow pressure distribution over noncircular cylinders at various flow incidence angles. The inviscid solution has been obtained by replacing the surface of a noncircular cylinder with a vortex sheet. The surface has been approximated by a number of flat panels. Each vortex panel has been assumed to have a constant vorticity, and the condition of no-circulation applied. Solutions yield the local tangential velocity and pressure coefficient at each point. The accuracy of the method has been established through comparison of the predicted results with existing exact theoretical results.

Comparisons of the predicted inviscid results with experimental data for square and triangular cross-sectional cylinders with rounded corners have also been included. Details of the computer program developed to implement this method are described in Appendixes A and B, which include input and output examples for a sample problem.

ABSTRACT

INTERACTION OF A TWO-DIMENSIONAL TRANSVERSE JET WITH A SUPERSONIC MAINSTREAM

Gilbert O. Kraemer
Old Dominion University, 1982
ODU Director: Dr. Surendra N. Tiwari
NASA Director: Dr. R. Clayton Rogers

An experimental investigation of the interaction of a two-dimensional sonic jet injected transversely into a confined main flow has been conducted. The main flow consisted of a air at a Mach number of 2.9. The effects of varying the jet parameters on the flow field were examined using surface pressure and composition data. Also, the downstream flow field was examined using static pressure, pitot pressure, and composition profile data. The jet parameters varied were gapwidth, jet static pressure, and injectant species of either helium or nitrogen. The values of the jet parameters used were 0.039, 0.056, and 0.109 cm for the gapwidth and 5, 10, and 20 for the jet to mainstream static pressure ratios. The features of the flow field produced by the mixing and interaction of the jet with the mainstream were related to the jet momentum. The data were used to demonstrate the validity of an existing two-dimensional elliptic flow code.

ABSTRACT

NUMERICAL STUDY OF THE TURBULENT BOUNDARY LAYER IN A HYPERSONIC NOZZLE

Joan Patricia Gosink
Old Dominion University
ODU Director: Dr. G. L. Goglia
NASA Director: Julius E. Harris

A numerical study of the turbulent boundary layer in a hypersonic nozzle is presented. The boundary layer equations are solved by a second order, implicit finite difference scheme developed at Langley Research Center. The technique is applicable to laminar, transitional or turbulent compressible or incompressible boundary layer flows for planar or axisymmetric geometries. A technique is presented for utilizing experimental data to start the finite difference solution.

Turbulent boundary-layer measurements on axisymmetric nozzle walls at Mach Number 6 are presented and compared with numerical predictions obtained by starting the solution in the stagnation chamber and from a downstream experimental station. Accurate numerical predictions were obtained for all cases when the classical boundary layer equations were valid. The numerical solution utilizing local data to start the finite difference solution improves agreement with measured velocity improves agreement with measured velocity and temperature profiles and displacement thickness.

Boundary layer measurements and numerical results indicate that the Crocco-velocity relation relaxes from a quadratic-type variation toward a more linear variation as the pressure gradient relaxes to zero.

For low Reynolds number flows modification of the eddy viscosity model utilized in the present finite difference scheme improves the accuracy of the predictions. Local application of an approximate low Reynolds number eddy viscosity model indicates improved agreement in boundary layer thickness, displacement thickness, and momentum thickness.

4. Solid Mechanics: Composites, Shells, Beams,
Static, Impact, and Transient Loading

ABSTRACT

AN ANALYTICAL AND EXPERIMENTAL STUDY OF CLEARANCE AND BEARING-BYPASS LOAD EFFECTS IN COMPOSITE BOLTED JOINTS

Rajiv Vikas Arun Naik
Old Dominion University, 1986
Director: Dr. Ram Prabhakaran
Co-Director: Dr. John H. Crews, Jr.

A combined analytical and experimental study is conducted to determine the effects of clearance and bearing-bypass loading for mechanically fastened joints in composites. A simple method of analysis is developed to account for the nonlinear effects of bolthole clearance. The nonlinear load-contact variations for clearance-fit fasteners are also measured using specially instrumented fasteners. For a quasi-isotropic graphite/epoxy laminate, results show that the contact arc as well as the peak stresses around the hold and their locations are strongly influenced by the clearance. After a slight initial nonlinearity, the peak stresses vary linearly with applied load. The typical clearance levels are shown to have only a minor influence on the overall joint stiffness.

Quasi-isotropic graphite/epoxy laminates (T300/5208) are tested under combined bearing and bypass loading to study failure modes and strengths. Radiographs are made after damage onset and after ultimate load to examine the failure modes. Also the laminate stresses near the bolt-hole are calculated for each test condition, and then used with appropriate failure criteria to analyze the test data. The tension data show a linear interaction for combined bearing and bypass loading with damage developing in the net-tension mode and growing to failure in the same mode. Failure modes are more complex in compression. The compression bearing-bypass strengths for damage-onset show an unexpected interaction involving the bearing mode. Compressive bypass loads reduce the bearing strength by

decreasing the bolt-hole contact arc and thus increasing the severity of the bearing loads. Bearing damage-onset, for compressive bearing-bypass loads, causes a weakening of the offset-section leading to ultimate failure in the offset compression-bearing mode. Damage-onset is predicted reasonably well using the peak stresses at the hole. Strength predictions indicate that damage corresponding to ultimate strength is governed by the maximum stress near the hole.

This investigation will help improve the basic understanding of composite bolted joints and lead to better structural design procedures.

ABSTRACT

ANALYSES OF QUASI-ISOTROPIC COMPOSITE PLATES UNDER QUASI-STATIC POINT LOADS SIMULATING LOW-VELOCITY IMPACT PHENOMENA

Ajit Dhundiraj Kelkar
Old Dominion University, 1985
ODU Director: Dr. Ram Prabhakaran
NASA Director: Dr. W. Elber

Composite laminates have high strength to density ratios that make them attractive for use in aircraft structures. However, the damage tolerance of these materials is limited because they have very low ultimate strains, no plastic deformation range, and no usable strength in the thickness direction. These limitations are very obvious when laminates are subjected to impact loads. Due to these impact loads, laminates suffer visible and invisible damage. To improve the material performance in impact requires a better understanding of the deformation and damage mechanics under impact type loads.

In thin composite laminates, the first level of visible damage occurs on the back face and is called "back face spalling." A plate-membrane coupling model, and finite element model to analyze the large deformation behavior of eight-ply quasi-isotropic circular composite plates under impact type point loads are developed. The back face spalling phenomenon in thin composite plates is explained by using the plate-membrane coupling model and the finite element model in conjunction with the fracture mechanics principles. The experimental results verifying these models are presented. The study resulted in the following conclusions:

1. The large deformation behavior of circular isotropic membranes subjected to arbitrary axisymmetric loading can be obtained by solving a single nonlinear governing equation in terms of a radial stress.

2. Accurate large deflection behavior of circular quasi-isotropic T300/5208 laminates can be obtained by using a simple plate-membrane coupling model.
3. The functional form of deformed shape of the plate undergoing large deformations is different from the small deflection plate solution.
4. The back face spalling action in thin composite laminates is a spontaneous action and can be predicted by using the fracture mechanics principles.
5. Mixed mode (I and II) type deformations probably occur during back face spalling, however, mode I appears to govern the delamination growth during the spalling action.

ABSTRACT

THE EFFECT OF UNREINFORCED CUTOUTS ON THE BUCKLING OF THIN CONICAL SHELLS LOADED BY CENTRAL AXIAL COMPRESSION

Garla Arjuna
Old Dominion University, 1974
NASA Director: Dr. James H. Starnes
ODU Director: Dr. Kenneth H. Murray

Analytical trends for the linear bifurcation buckling of thin isotropic right-circular-conical shells with unreinforced cutouts are investigated. Clamped, constant-thickness conical shells with homogeneous, isotropical material properties are analyzed for uniform axial compression. The buckling loads are obtained by the use of the STAGS Structural Aalysis of General Shells) computer program which is based on a finite difference numerical approach. Variables defining the geometry of the cutout and the cone are nondimensionalized and the relationship between the nondimensional buckling load and nondimensional cutout parameter is established. A range of the cut out sizes is investigated for which linear bifurcation buckling results are expected to be reasonable approximations to the actual buckling loads.

ABSTRACT

AN EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF THE IOSIPESCU SHEAR TEST FOR COMPOSITE MATERIALS

Barry Stuart Spiegel
Old Dominion University, 1984
ODU Director: Dr. R. Prabhakaran
NASA Director: Dr. James W. Sawyer

Mechanical properties of composite materials under shear loading are difficult to determine. The Iosipescu Shear Test, originally proposed for metals, has in recent years been applied to composites. It has the advantages of small specimen size, simple loading and a reasonably uniform shear stress in the test section.

The purpose of this work is to study the validity of the Iosipescu test method for measuring the shear modulus and shear strength of composites. Finite element analyses indicate that optimum specimen geometry and load locations depend upon the degree of orthotropy of the composite. Test results for a quasi-isotropic graphite/epoxy laminate show that modifications in the notch geometry aimed at improving stress distributions result in unexpected changes in the failure mode. Thus, while the Iosipescu Shear test is valid for some composites with a suitable choice of test parameters, its validity for other composites, especially with a higher orthotropy, is doubtful.

ABSTRACT

FINITE ELEMENT MODEL OF A TIMOSHENKO BEAM WITH STRUCTURAL DAMPING

Louis Ablen Roussos
Old Dominion University, 1980
Director: Earl A. Thornton
NASA Director: Dr. E. T. Kruszewski

A numerical integration technique, a modified version of the Newmark method, is applied to transient motion problems of systems with mass, stiffness, and small nonlinear damping. The nonlinearity is cast as a pseudo-force to avoid repeated recalculation and decomposition of the effective stiffness matrix; thus, the solution technique is dubbed the "pseudo-force Newmark method." Comparisons with exact and perturbation solutions in single-degree-of-freedom problems and with a Gear-method numerical solution in a cantilevered Timoshenko beam finite element problem show the solution technique to be efficient, accurate, and, thus, feasible provided the nonlinear damping is small. As a preliminary step into the investigation of the active control of large space structures, a problem involving a free-free Timoshenko beam with nonlinear structural damping is solved. As expected, small damping is shown to be of little importance in the prediction of low-frequency vibrations while being of utmost importance in the prediction of high-frequency vibrations.

5. Instrumentation
and Measurement
Techniques

ABSTRACT

STATIC TEMPERATURE MEASUREMENTS IN SUPERSONIC FLOW USING LASER RAMAN SPECTROSCOPY

Paul A. Nystrom
Old Dominion University, 1977
ODU Director: A. S. Roberts. Jr.
NASA Director: Dr. J. M. Seiner

Laser Raman spectroscopy is a nonintrusive technique which can generate mean static temperature (MST) data within flow fields. By ratioing two simultaneously gathered portions of the Raman scattered spectrum, absolute intensity measurements were not needed. This method was applied to a supersonic cold air jet, $M = 1.99$, where the MST ranged from 160°K to 300°K. Accurate measurements were not realized due to the presence of flow contaminants, especially water vapor.

ABSTRACT

A HIGH-SPEED ALGORITHMIC SIGNAL PROCESSOR

Stephen P. Livingston
Old Dominion University, 1978
ODU Director: Dr. Muralidhara Varanasi
NASA Director: Mr. Patrick Gaines

Microprocessors are now being used in the implementation of solutions to many classes of problems, but in some cases the microprocessor is not sufficient due to the lack of processing speed of large-scale integrated circuitry. A possible solution is presented using a hardware algorithmic signal processor to take the place of time-consuming software routines, leaving the microprocessor the task of controlling operations within the system. The hardware processor consists of a high-speed multiplier as the central unit and high-speed Schottky logic, all under microprogram control. Several classes of algorithms are considered for implementation as a microprogram for the evaluation of transcendental functions and floating point arithmetic using the multiplier as the central unit. Design considerations include high speed, which will be evaluated for the system, and small size, which means a decrease in integrated circuit package count.

ABSTRACT

SECOND ORDER OPEN LOOP OMEGA PHASE DETECTOR: MICROPROCESSOR-BASED

Phillip S. Mastic
Old Dominion University, 1978
ODU Director: Dr. Preston B. Johnson
NASA Director: Mr. Carroll Lytle

A microprocessor-based open loop OMEGA phase detector has been investigated and experimentally verified. The microprocessor's ability to perform the required phase detection algorithms in software drastically reduces hardware complexity providing an OMEGA navigation receiver design of lower cost. Also, algebraic manipulation of the quantized phase error by the processor linearizes the phase detector characteristic curve.

This thesis describes the theory and implementation of this open loop technique and a comparison is made with a standard digital phase-locked loop. A brief review of the OMEGA navigation system is presented followed by a discussion of the current receiver developed by personnel at NASA Langley Research Center. Succeeding chapters document theoretical and experimental efforts made in support of the goal to upgrade the phase detector section in the current NASA receiver.

ABSTRACT

THE DEVELOPMENT OF A MICROPROCESSOR CONTROLLED LINEARLY ACTUATED VALVE ASSEMBLY

Raymond H. Wall
Old Dominion University, 1984
ODU Director: Dr. Robert L. Ash
NASA Director: Dr. Ping Tcheng

The development of a proportional fluid control valve/assembly is presented. This electro-mechanical system is needed for space applications to replace the current proportional flow controllers that use bulky hydraulic or pneumatic actuation systems. The flow is controlled by a microprocessor system that monitors the control parameters of upstream pressure and requested volumetric flow rate. The microprocessor achieves the proper valve stem displacement by means of a digital linear actuator. A linear displacement sensor is used to measure the valve stem position. This distance is monitored by the microprocessor system as a feedback signal to make the control closed-loop. With an upstream pressure between 15-47 psig, the developed system operates between 779 standard cm³/sec (SCCS) and 1543 SCCS. The delivered volumetric flow rates were within 5% of the requested values. A statement on the system stability is included as an appendix. Recommendations made for future work on the design include further modification to the bellows spring and the possibility of a mass flow rate controller.

6. Thermophysical Properties Experiments

ABSTRACT

A METHOD FOR IMPROVING THE ACCURACY IN PHASE CHANGE HEAT TRANSFER DATA THROUGH INCREASED PRECISION IN THERMOPHYSICAL PROPERTY DETERMINATIONS

John Philip Drummond
Old Dominion University, 1975
ODU Director: Dr. Robert L. Ash
NASA Director: Mr. Robert A. Jones

Wind tunnel model materials typically have thermophysical properties that vary with both position and temperature. A numerical study using a finite difference representation of the heat conduction equation has been performed on several of these model materials to determine their thermal response under a specified heat loading. This study has confirmed the feasibility of using an effective thermophysical property to account for the existence of variable thermal properties when a model undergoes aerodynamic heating. The effective property, when used in the reduction of phase-change heat transfer data, forced agreement of the actual transient behavior of a model with the constant property semi-infinite slab approximation traditionally used to describe model response. Results of the numerical study have also been compared with similar data from an experimental apparatus currently being developed at NASA Langley Research Center. Knowledge gained from the comparison has been used to formulate methods for improving the performance of the experimental apparatus.

ABSTRACT

TEMPERATURE AND TIME DEPENDENT VISCOSITY OF AN ELASTOMER-MODIFIED EPOXY RESIN

Woodrow W. Wagner, Jr.
Old Dominion University, 1978
ODU Director: Dr. John K. Kuhlman
NASA Director: Howard Price, Jr.

Temperature effects on the viscosity of an epoxy resin (diglycidyl ether of bisphenol A - DGEBA), an elastomer (carboxy-terminated butadiene acrylonitrile - CTBN), and two blends nominally containing 10 percent elastomer were examined from strain rates of 0.1 sec^{-1} to $10,000 \text{ sec}^{-1}$ over a temperature range from 300K to 450K. All results indicated that the greatest drop in viscosity occurred for each of the materials over the temperature range of 300K to 350K. In addition, the materials exhibited Newtonian responses over the entire strain rate range. Adding small amounts of elastomer to the epoxy only moderately affected the viscosity; whereas the catalyst, triphenylphosphine, added to one of the blends did not measurably change the viscosity. Activation energies over the test temperature range were calculated using the Arrhenius relationship between viscosity and inverse temperature. Two distinct activation energies were found for each material in the temperature ranges 300K to 350K and 400K to 450K, indicating the existence of two different molecular flow mechanisms in these two temperature ranges.

An elastomer-modified epoxy resin and the epoxy resin by itself were tested at constant strain rates as a function of time under conditions of room temperature (300K). Properties of thixotropy and rheopexy were found, observed, and analyzed. Each particular strain rate contained its own characteristic relaxation and recovery times for a particular material. The elastomer showed no time-dependent effects up to a strain rate of 100 sec^{-1} ; reliable data could not be obtained at higher strain rates.

7. Large Space Structures: Dynamics,
Control, Reliability Analysis

ABSTRACT

OPTIMAL CONTROL OF A LARGE SPACE TELESCOPE USING AN ANNULAR MOMENTUM CONTROL DEVICE

Arun Anant Nadkarni

Old Dominion University, 1977

ODU Director: Dr. W. J. Breedlove, Jr.

NASA Director: Dr. W. W. Anderson and Mr. Nelson J. Groom

Application of a new development in the field of momentum storage devices, the Annular Momentum Control Device (AMCD), to the twin problems of large angle maneuvers and fine pointing control is considered. The basic concept of AMCD consists of a spinning rim, with no central hub area, suspended by a minimum of three magnetic bearings, and driven by a noncontacting electromagnetic spin motor. The dissertation considers in detail the application of the AMCD to achieve both the large angle maneuvers and the fine pointing control of a Large Space Telescope (LST) with a single configuration, consisting of a single AMCD Mounted in a single gimbal.

The problem of designing the optimal controller is accomplished in two parts: 1) the optimal controller for generating the open-loop control law for the nonlinear maneuvering problem was designed using a modified gradient technique with penalty functions, 2) the optimal stochastic controller for generating the constant gain, state feedback control law for the linear fine pointing problem was designed.

The open-loop optimal control for the maneuvering problem was derived iteratively, using a modified gradient technique with penalty functions. "Hard" constraints on magnitudes of state and control variables were incorporated in the gradient procedure. A general, user-oriented computer program was developed to derive open-loop optimal control law history using

this procedure for a general high order (up to 25) nonlinear system. The program was used to achieve the design objective of deriving the open-loop optimal control law to retarget the LST from one stellar target to another with the expenditure of minimum energy. A specific example problem of maneuvering the LST through prescribed pointing angles was solved. Convergence of the iterative procedure to a local minimum was shown to be highly dependent on the initial control history chosen and choice of weighting matrices.

The optimal state feedback control law for the fine pointing controller was derived using Linear-Quadratic-Gaussian (LQG) optimal regulator theory. Structurally, this controller consists of an optimal regulator and a Kalman-Bucy filter. Existing techniques to compute the initial stabilizing gains and iterative procedures to solve the algebraic Riccati equation were discussed. Extension of these techniques to the present problem, which is uncontrollable, was indicated by discussing the modifications of the state equations required to make the regulator problem stabilized. It was shown that the initial errors in the states can be nulled satisfactorily. The performance of the fine pointing controller was investigated by performing a linear covariance analysis to obtain the RMS pointing errors. The analysis indicated that fine pointing accuracies of less than one arcsecond could be achieved.

ABSTRACT

AN APPROACH FOR INCLUDING RELIABILITY IN CONTROL SYSTEM DESIGNS

Ime Isaac Akpan
Old Dominion University, 1982
ODU Director: A. Sidney Roberts, Jr.
NASA Director: Raymond C. Montgomery

An approach is developed for non-catastrophic control component failure accommodation for large space structures. Reliability is considered for both the control configuration (i.e., selecting actuator locations over an admissible set) and the ultimate operation of the system. The approach presented is to construct a measure of performance that indicates the absolute goal of the system, and for a given structural design, to determine the lowest achievable cost conditional upon the failure states of the system (i.e., which actuators are operational). These costs are then weighted and summed to provide an overall system performance measure. This expected performance measure is then minimized over the set of admissible control configurations. A complete mathematical development is presented for a flexible beam and a grid structure. The optimal configurations for the failure states are determined for different normalized time of mission. Although the research is concerned with a particular problem, the analysis of the reliability incorporation in the design of control systems is of more general interest.

8. Earth Orbital Dynamics

ABSTRACT

DYNAMICS OF EXPLOSION REMNANTS IN EARTH-ORBITS

Joseph T. Fuss
Old Dominion University, 1974
NASA Director: Mr. J. M. Alvarez
ODU Director: Dr. W. J. Breedlove, Jr.,

Explosions in space produce particles that are hazardous to space vehicles. Some of these particles are not trackable and their locations must be predicted by dynamical methods.

This investigation sheds light on three different areas. First, ignoring perturbations, the characteristics of a three dimensional envelope outlined by the sum of individual particle orbits is determined. Second, the distribution of the particles is found as a function of time. Finally, the movement of the body via secular perturbations is investigated. Magnitudes of the explosion, the point of detonation in the parent satellite's orbit, and the radius of perigee of the parent satellite are varied as parameters.

It was found that the particles evenly distributed themselves throughout the envelope, with areas of higher density due to its shape. Perturbations caused drastic changes in the size and orientation of the envelope, thereby complicating the prediction of the areas of higher density.

ABSTRACT

DYNAMIC ANALYSIS OF AN EARTH-ORBITING SATELLITE DEPLOYING HINGED APPENDAGES

Kevin Fielding Oakes
Old Dominion University, 1986
ODU Director: Dr. Chuh Mei
NASA Director: Dr. J. M. Housner

The planar librational dynamics of an arbitrary spacecraft with deployable hinged appendages is presented here both analytically and numerically. The system model consists of a central rigid satellite moving about the earth in a circular orbit at a uniform orbital rate. Attached to the satellite are two unfolding rigid booms with specified mass and length. Tip masses are included at the ends of each boom and deployment is driven by torsional springs at both frictionless hinge points. The equations of motion are developed for both a single- and double-appendage model through the use of Lagrange's equations. The formulation accounts for large angle rotations, Coriolis effects, and the gravitational gradient. Utilizing Newtonian mechanics, the equations of motion for the deployment of a single massless boom are developed and compared with the Lagrangian formulation for validation purposes. The resulting nonlinear, coupled governing equations are not subject to closed-form solutions and are thus integrated numerically. Nondimensional parameters are defined to simplify the single appendage analysis and the equations are linearized about prescribed positions to study the stability of the system. The investigation is applied to the Space Shuttle based deployment of rigid truss-like members. Results indicate that spacecraft inertia parameters, appendage mass and length, deployment velocity, and initial conditions all exhibit considerable influence on the system response. The resulting librational motion is directly related to the size of the deployable payload and gravitational

forces lead to vehicle stabilization. These findings may be helpful in assessing orbital effects during the deployment of large space structures or on the motion of satellites with robotic manipulator arms.

9. Environmental Engineering:
Water Quality Modeling
and Atmospheric Radiation Process

ABSTRACT

A MODEL TO INVESTIGATE THE INFLUENCE OF SUSPENDED SEDIMENT ON THE MASS TRANSPORT OF A POLLUTANT IN OPEN CHANNEL FLOW

Raymond Scott Chapman
Old Dominion University, 1977
ODU Director; Dr. Chin Y. Kuo
NASA Director: Charles Whitlock

The environmental impact of the transport of pollutants in open channel flow has for many years been of interest due to the continuous introduction of heavy metals, pesticides, herbicides, and other foreign substances into natural waterways. In order to fully understand this transport process, it is necessary to examine the significance of its individual components. In the present study an explicit two-dimensional finite difference model, designed to investigate the influence of suspended sediment on the pollutant transport process, is presented. Specific attention is directed toward examining the role of suspended sediment in 1) the turbulent vertical transport mechanism in a stratified flow, and 2) pollutant uptake due to sorption. Results presented indicate that suspended sediment plays a major role in the pollutant transport process, and subsequently, any meaningful attempt to model the fate of a pollutant in an alluvial channel must account for the presence of a suspended sediment concentration profile. Similarly, the vertical and longitudinal pollutant concentration distributions provided by the model may be utilized to improve upon the predictive capacities of existing water quality models.

ABSTRACT

EFFECTS OF MULTIPLE SCATTERING AND SURFACE ALBEDO ON THE PHOTOCHEMISTRY OF THE TROPOSPHERE

Tommy Reinhold Robert Augustsson
Old Dominion University, 1981
ODU Director: Dr. Surendra N. Tiwari
NASA Director: Dr. Joel S. Levine

A one-dimensional photochemical model of the troposphere containing the species of the nitrogen, oxygen, carbon, hydrogen, and sulfur families has been developed and used to investigate the vertical profiles and the natural (including atmospheric chemical reactions) and anthropogenic sources and sinks of these species. The species continuity equations are solved numerically applying prescribed boundary conditions. The vertical flux is simulated by use of the parameterized eddy diffusion coefficients. Heterogeneous losses (e.g. rainout, gas-to-particle chemistry, and dry deposition), are parameterized to make calculated profiles consistent with measurements. The photochemical model is coupled to a radiative transfer model that calculates the radiation field due to the incoming solar radiation which initiates much of the photochemistry of the troposphere. Comparisons of vertical profiles of tropospheric species are made between the Leighton approximation, widely used in most tropospheric models, and the detailed radiative transfer matrix inversion model used in this study. The radiative transfer code includes the effects of multiple scattering due to molecules and aerosols, pure absorption and surface albedo on the transfer of incoming solar radiation. The results indicate that significant differences exist for several key photolysis frequencies and species number density profiles between the Leighton approximation and the profiles generated with the more detailed radiative matrix inversion technique used in this study. Most species show enhanced vertical profiles when the more realistic treatment of

the incoming solar radiation field is included. Furthermore, most species increase in concentration as a function of increasing surface albedo. A few species, notably ozone, exhibit decreased levels of concentration when the realistic radiative transfer model is used. The effect of the detailed treatment of incoming solar radiation on the photochemistry of the troposphere is discussed.

ABSTRACT

EVALUATION OF UPWELLING INFRARED RADIANCE IN A NONHOMOGENEOUS NONEQUILIBRIUM ATMOSPHERE

Sundaresa Venkata Subramanian
Old Dominion University, 1976
ODU Director: Dr. S. N. Tiwari
NASA Director: Dr. H. G. Reichle

The primary purpose of this study was to investigate the influence of vibrational nonequilibrium upon upwelling infrared radiance from the Earth's atmosphere. Basic equations are presented for calculating the atmospheric transmittance, heating rates, and equilibrium and nonequilibrium upwelling radiances. By employing the Lorentz line-by-line model for spectral absorption, heating rates and upwelling radiances were calculated for equilibrium as well as nonequilibrium conditions in the spectral range of 4.6μ CO and 3.3μ CH₄ bands. For the spectral range of CO fundamental band, the influence of different parameters on the upwelling radiance was also investigated. The results indicate that for CO the assumption of LTE is not justified at tropospheric pressures and temperatures. For CH₄, however, the assumption is justified up to 60 kilometers. This information is very useful in developing an accurate data reduction scheme for the measurement of CO and CH₄ concentrations in the atmosphere.

APPENDIX B

Published and Presented Papers (Chronological Order)

Harvey, William D., Berger, Michael H., and Stainback, P.C., "Experimental and Theoretical Investigation of a Slotted Wall Noise Shield Model," Proceedings of the 8th Aerodynamic Testing Conference, Bethesda, Maryland, July 8-10, 1974.

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Augustsson, T., and Ramanathan, V., "A Radiative-Convective Model Study of CO₂ Climate Problem," Journal of the Atmospheric Sciences, Vol. 34, No. 3, March 1977.

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Crews, J. H., and Naik, Rajiv V. A., "Failure Analysis of a Graphite/Epoxy Laminate Subjected to Bolt Beaming Loads," NASA Technical Memorandum 86297, Hampton, Virginia, Aug. 1984.

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